AERIAL DISPERSAL OF THE PINK BOLLWORM IN THE UNITED STATES AND MEXICO

Production Research Report No. 96

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
In Cooperation With
Texas Agricultural Experiment Station

ACKNOWLEDGMENTS

Thanks and appreciation are extended to the following individuals for furnishing data, notes, and helpful suggestions:

Personnel of the Plant Pest Control Division, Entomology Research Division, and Plant Quarantine Division, all of Agricultural Research Service.

U.S. Weather Bureau, especially E. G. Bice, A. W. Brooks, R. L. Fox, Ray Guenzi, S. L. Hardy, P. C. Kangiesser, H. E. Landsberg, and G. E. Stegall.

W. T. Mendenhall and R. Miller, Arizona Commission of Agriculture and Horticulture.

G. P.Wene, Arizona Agricultural Experiment Station.

C. A. Lincoln and R. C. Hunter, Arkansas Agricultural Experiment Station.

Truman Hill, Arkansas Plant Board.

H. B. Mills, G. C. Decker, and H. N. Ross, Illinois State Natural History Survey.

L. D. Newsom, J. S. Roussel, and F. S. Cullahan, Louisiana Agricultural Experiment Station.

H. G. Johnston, National Cotton Council of America.

J. G. Watts, New Mexico State University.

F. A. Fenton (retired), Oklahoma State University.

V. A. Little (retired), D. F. Leipper, and G. W. Schlesseman, Texas A&M University.

W. C. Wellington, Canada Department of Forestry.

W. C. Jacobs, Library of Congress.

W. D. Sellers, University of Arizona.

A. A. Stanley, U.S. Coast and Geodetic Survey.

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Washington, D.C. Issued January 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 10 cents.

AERIAL DISPERSAL OF THE PINK BOLLWORM IN THE UNITED STATES AND MEXICO

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INTRODUCTION

The pink bollworm [*Pectinophora gossypiella* (Saunders)] was presumably introduced into Mexico in 1911, in cottonseed shipped from Egypt. Later the pink bollworm spread from Mexico to the United States. Various records indicate that much of the spread was due to flight of the moths or to their being carried on the wind. The pink bollworm is also known to have been transported in cottonseed, lint, linters, byproducts, and contaminated cotton bagging, as well as in bolls carried by waters draining from infested fields, particularly during heavy rains.

In areas of the United States and Mexico under quarantine, localized infestations are probably dispersed by flights of moths or by their being carried on the wind. For that reason, quarantine measures in infested areas and inspections in uninfested areas should be continued. These procedures, along with appropriate control measures, are most important in checking the spread of the insect beyond its area of natural dispersal.

The pink bollworm is not considered a true migrant in the same sense as are certain species of butterflies or the cotton leafworm [*Alabama argillacea* (Hübner)]. In this report, the term "migration" is used to designate the long-range movement of the insect. Dispersal of insects over long distances can be accomplished by "active" or "passive" means. "Active" refers to flight of the insect by itself, and "passive" to mechanical carriers or to being carried on air currents.

Some of the records discussed in this report have been published; others are from notes made by workers at field stations and laboratories; still others are from reliable sources as personal communications with USDA and State university personnel who have worked with or studied this pest. To better understand how the spread of the pink bollworm occurred, the author has endeavored to correlate these records with his own observations and to relate them to the history associated with the distribution of the pink bollworm in both Mexico and the United States.

AERIAL DISPERSAL AND METHODS OF DETERMINING PRESENCE AND ACTIVITY OF MOTHS

Special equipment and techniques are often necessary to determine the presence and activity of pink bollworm moths, especially when their populations are low. By planting small plots of cotton in isolated areas and by using light traps and traps installed in airplanes for collecting moths and other insects as well, many workers collected data. These data, correlated with additional information pertaining to the history and progression of the pink bollworm in the United States, can give a fairly complete understanding of how the insects disperse. The techniques and equipment used for obtaining this information are discussed under the various headings included in this section of the report.

Evidence From Isolated Plantings of Cotton

Noble (*18*) [1] reported that 18 of 90 trap plots planted on isolated ranch lands north of the cotton acreage in the Big Bend area of Texas and Mexico became infested with the pink bollworm. Studies showed that plots near Van Horn, 35 miles from the nearest cotton in the Presidio Valley, also became infested in 4 of 6 years. Some of the infested plots were about 65 miles from the nearest cotton.

In the mountainous section north of the Big Bend area of Texas, several examples of unques-

[1] Italic numbers in parenthesis refer to Literature Cited, p. 12.

tionable migration of moths were noted by L. D. Harris, Plant Pest Control Division (PPCD), USDA, retired (personal communication). Late in August 1952, he observed that at Alpine a small planting in a yard (grown from noninfested seed) was infested with the insect. The nearest cotton then infested with pink bollworm was some 50 miles east of Alpine. In 1956, a planting of six stalks of cotton at Alpine became infested late in October. That year the nearest heavily infested cotton was 60 miles southwest of Alpine. In 1956, cotton was planted for the first time in many years on a farm 11 miles southeast of Marfa. In late fall, it became infested by both pink bollworm and boll weevil (*Anthonomus grandis* Boheman). Apparently both species were migrants carried by prevailing winds coming from the Presidio Valley, some 50 to 60 miles (by air) south of the Marfa farm. Also, in September 1956, pink bollworms had infested the bolls of a lone cotton plant observed north of Fort Davis, located 25 miles from the Marfa planting and about 85 miles north of the heavily infested Presidio Valley (fig. 1).

D. H. Currie, L. F. Curl, D. M. McEachern, J. S. Parker, and W. P. Patton, all of PPCD, USDA (personal communications), reported a cotton plant infested with pink bollworms. The plant was growing in an isolated field of a 3-acre dryland farm at Ejido El Paso, near Culiacan, Sinaloa, Mexico, about 255 miles west of Torreon (fig. 1). On October 10, 1957, PPCD (USDA) inspectors (while making field inspections in an area about 20 miles north of Culiacan) found a total of 13 pink bollworms in 3 blooms, 5 green bolls, and 3 squares on the single plant. After they discovered the infestation they thoroughly inspected the field, plant by plant, but found no further infestation. The cotton, planted by local people, had always been harvested by pickers from that area. Because this particular area was so isolated, the PPCD inspectors concluded that the wind had carried a moth (or moths) into the field

FIGURE 1.—Main area of pink bollworm infestation in North America, exclusive of Florida.

and that the insect (or insects) had been transported about 150 miles from cotton known to be infested with pink bollworms and growing in the State of Durango. A gravid moth (or male and female moths) had apparently dropped from the air near this particular plant and the progeny caused the infestation. Annual intensive inspections in this and other fields of the area have failed to reveal any further evidence of pink bollworms through 1965.

Evidence From Light Traps

Light traps have been used to detect the occurrence and dispersal of pink bollworm moths in many areas. Glick and Hollingsworth (*8*), who operated traps in the lower Rio Grande Valley during the summer and fall of 1952, collected many pink bollworm moths; they trapped more moths in late August than in any other month. During one night (August 28), immediately after cotton stalks in the area had all been destroyed, they collected an estimated 96,000 pink bollworm moths. The following night, they collected only 1,715, and 8 days later (September 6) only 34. They concluded that because the cotton stalks had been completely destroyed, the moths had taken flight to another area more promising. Since at this time the prevailing wind was south southeast, they probably dispersed in a northerly direction.

During the late summer of 1952, Glick and Hollingsworth (*8*) collected pink bollworm moths from light traps placed in the northeastern part of Texas; before this time the area had not been known to be infested. Their finding indicated that moths had migrated into the area. The moths were probably carried by the southerly winds from a heavy infestation on late cotton in the Corpus Christi area that was present in the fall of 1951.

During August to October of 1960 and 1961, P. A. Glick and H. M. Graham, Entomology Research Division, USDA, (unpublished) collected pink bollworm moths from a blacklight trap equipped with an argon-glow lamp. They concluded that this field, located 74 miles north northwest of Brownsville, near the King Ranch of Texas, was infested with moths that had dispersed from the cotton-growing area of the lower Rio Grande Valley of Texas, a distance of more than 25 miles.

Glick (*7*) also reported that in 1958 through 1962 the use of light traps helped him determine whether pink bollworm moths were present in cottonfields of Arizona. Traps were operated by the Plant Pest Control Division in Maricopa and Pinal Counties, as well as at points south to Tucson, northeast to Safford, and southwest to the Yuma area (fig. 2). Moths were collected throughout the area. Since two specimens were taken at Yuma, it is concluded that the moths had probably dispersed throughout the entire area where the traps had been placed.

During 1959 and 1960 the author, working in the mountainous and desert areas of Arizona, assisted in taking collections of insects that included pink bollworm moths. Several moths were taken in traps located in canyons of the Rincon and Santa Rita Mountains as well as in the Molina Basin, a few miles north of Tucson near Mount Lemmon (fig. 2). Although wild cotton (*Gossypium thurberi* Todar) was growing in the canyons, the moths probably did not originate from this secondary host. Only one pink bollworm has ever been recorded in Arizona on this host (*24*). Therefore, one can logically assume that the moths trapped had been carried by prevailing winds, which brought them from infested cotton located some 15 or more miles from the points where the traps were located.

Evidence From Traps Baited With Sex Attractant

Ouye and Butt (*19*) discovered the presence of a natural sex attractant in female pink bollworm moths at the Southwestern Cotton Insects Investigations Laboratory in Brownsville, Tex. The researchers extracted the attractant from the abdominal tips of female moths, and Graham and Martin (*11*), of the same laboratory, designed special traps containing the extracts that could be used to trap the males. Since the extract attracts only male pink bollworm moths, Graham and Martin were able to eliminate the trapping of most other insects (not possible with light traps). Occasionally a few Microlepidoptera (undetermined species) were trapped, but these may have flown into the traps to rest or conceal themselves. However, Graham and Martin collected quite a few specimens of a gelechiid moth [*Filatima albipectus* (Walsingham)], (especially in the cotton areas of Arizona) in about equal numbers of each sex. This species occurs mostly in the Southwest, and the larva is associated with mesquite (*Prosopis*), *Mimosa*, etc.

Traps baited with sex lure have been used in Texas at Brownsville, in Arizona at Bard, and in California at Blythe; they were also located at a point across the Colorado River from Yuma County, Ariz., and in the vicinity of Torreon, Mexico. Such traps proved to be an excellent survey tool for determining the presence of infestations and the seasonal activity of the moths. These traps are much less expensive and easier to operate than light traps.

Evidence From Flight Screens

From time to time, the use of screens is an excellent way to determine the relative abundance and activity of moths. Screens do not necessarily pro-

FIGURE 2.—Arizona and western New Mexico, showing course of Continental Divide.

vide evidence of migration but their use helps in interpreting other data.

Fenton and Owen (*3*) used flight screens; their data indicated that moths travel both with and against mild air currents near the earth's surface. By collecting pink bollworm moths in light traps, Glick and Hollingsworth (*9*) also found that the greatest number of moths collected flew into a mild prevailing wind with a velocity of 3 miles or less per hour. Results of laboratory experiments with a wind tunnel (*9*) demonstrated that the moths could not regulate their flight when the airstream was above 3 miles per hour. Since prevailing winds are usually above this velocity, the moths must be carried on the wind in their dispersal flights.

Evidence From Airplane Collections

Data pertaining to collections of pink bollworm moths taken in an airplane are given in table 1. As early as 1928, this type of collection was made in the Laguna area of Mexico, 200 miles south of the Big Bend area of Texas. Moths were taken at altitudes up to 3,000 feet (*4*). Results of this work, as well as the observations of other investigators familiar with the area, indicated that in the United States, moth flight, aided by air currents, has helped considerably in the spread of pink bollworms into the Big Bend area and northward.

In 1954, Glick (*5*, *6*) collected the pink bollworm in an airplane flying over the lower Rio Grande Valley and the King Ranch area (fig. 1.) The King Ranch area, a semiarid, mostly desolate region with no land under cultivation, is used only as a cattle range. The author took a pink bollworm moth there at 1,000 feet when the wind was from a southerly direction. Only moth flight or transport by air currents could account for the capture here, since the occasional wild host plants of this particular area are not known to be infested.

In 1956, insect-collecting flights were made in central Texas, Louisiana, Arkansas, and Oklahoma (*10*). Several pink bollworm moths were taken in the central Texas area. The surface wind direction at time of collection was southerly. They concluded that the moths drifted or were carried by wind to the north and northeast from the heavily infested area in central and southern Texas. Turbulent weather influenced moth movement. During passage of a cold front, a pink bollworm moth was trapped at 2,000 feet while the plane was flying over the fringe of the infested area in northwestern Louisiana and Arkansas. Although the source of this specimen cannot be determined for certain, the moth probably came originally from the central Texas area, was carried in a northeasterly direction into the path of the cold front, and then forced up into the temperature-inversion layer at 2,000 feet. When the weather was rough, more than five times as many insects were trapped at this altitude as on the preceding day during calm weather at the same time and altitude. Collections made under these conditions show the importance of weather conditions in dispersal and spread of insects.

TABLE 1.—*Airplane flights and number of pink bollworm moths collected in the upper air in Mexico and the United States*

Location of flight and date	Number of flights made	Number of moths collected at indicated altitude								
		20 feet	100 feet	200 feet	500 feet	1,000 feet	2,000 feet	3,000 feet	4,000 feet	5,000 feet
Tlahualilo, Durango, Mexico: August and December 1928	44	4	1	-------	0	1	0	1	0	------
Lower Rio Grande Valley, Tex.: August and September 1954	46	-----	4	3	2	2	0	-------	------	0
King Ranch area, Tex.: August and September 1954	9	-----	0	0	0	1	0	-------	------	0
Central Texas area: August to October 1956	78	-----	-----	3	8	3	2	0	------	------
Northwestern Louisiana and southwestern Arkansas: August to October 1956	22	-----	-----	0	1	0	1	0	------	------
Total	199	4	5	6	11	7	3	1	0	0
Total flying time (minutes)	--------	350	601	2, 022	2, 471	2, 807	2, 075	1, 770	110	630

ABILITY OF MOTHS TO BECOME ESTABLISHED AFTER DISPERSAL

Can a pink bollworm moth survive and reproduce after it has flown or been carried long distances? To answer this question, researchers have simulated in the laboratory some of the conditions (temperature, relative humidity, and barometric pressure) to which moths would be subjected during dispersal flights.

Noble (*17*) studied the responses of pink bollworm moths to conditions simulating those at altitudes up to 3,000 feet. During periods ranging from 1 to 7 days, the moths suffered no ill effects from exposure to icebox temperatures averaging 60° F., with an average relative humidity of 58.4 percent. The moths remained in good condition;

after exposure, the females were able to begin or resume oviposition of fertile eggs. Since the average air temperature at 3,000 feet in the El Paso and Presidio areas was 64° in August and 61° in September, these weather conditions closely approximated those of the experiment.

Wellington (*25*) reported that, under flight conditions, changes in relative humidity seem to have slight effect upon the average insect except in freezing temperatures when the air is saturated. He further stated: "Although low temperature acts as a limiting factor to flight, the passive population of the convective zone is not likely to be injured or killed by large decreases in temperature, since the time of exposure to any given temperature is of such short duration." However, if insects were caught and carried in the current of a prevailing wind at a given high altitude and remained for long in an area of lethal temperature, they would doubtlessly be killed. Many insects can survive under extreme changes in temperatures for a reasonable time.

Packchanian and Pinkerton (*20*) conducted experiments relating to temperature and barometric pressure with several insects. Subjecting insects to barometric pressures which corresponded to those at altitudes of 10,000 and 30,000 feet, Packchanian and Pinkerton found that low temperature rather than reduced pressure was responsible for the detrimental effect. Thus if any pink bollworm moths were carried upward to altitudes as high as 10,000 feet above sea level, they would probably survive unless they were subjected to severe weather conditions, such as rain and hail storms or very turbulent air currents. If gravid moths are able to reach the earth again without too prolonged a flight or without being subjected to other unfavorable conditions, they should be able to establish new populations in new areas. Quite probably, one explanation for establishment of the insect lies in its ability to survive under such conditions, especially in areas where the source of infestation could not otherwise be determined.

DISPERSAL AND SPREAD OF MOTH

The history of this expanded distribution of the pink bollworm explains the probable means by which the spread took place. Although much of the following discussion is theoretical, and based on circumstantial evidence, the author believes that it is a fairly accurate interpretation of how the pink bollworm has become distributed.

Since the pink bollworm was introduced in Mexico, a continuous battle has been waged to prevent the insect from becoming established throughout the cotton-growing areas of that country and the United States. However, the insect now infests areas in Arizona, New Mexico, Texas, Oklahoma, and intermittently in areas of Arkansas and Louisiana; it also infests wild cotton and other host plants at the tip of Florida. The infestation in Florida is not related to that in Mexico or that in the Southwestern United States.

Extent of Infestation in Mexico

In 1911, the pink bollworm was introduced into the Republic of Mexico via at least one of two shipments of cottonseed being imported from Egypt. One shipment consisting of 125 sacks of cottonseed was planted near Monterrey in the State of Nuevo Leon. Another shipment, obviously infested, was planted near San Pedro, State of Coahuila, in the Laguna area (*13*, *14*). We have no records to indicate that the pink bollworm became established near Monterrey as a result of the planting of Egyptian seed received there in 1911. However, specimens identified as pink bollworms were collected in the fall of 1916 from a plantation in the Laguna area in the northern part of the country (*13*). Therefore, we know that in Mexico the insect did not become sufficiently abundant and was not recognized as a serious pest of cotton until 1916 (*23*).

Through the shipment of cottonseed from one part of the Laguna to another and possibly through flight of the insect, the pink bollworm eventually became established throughout the area (*12*). The infestation of the early years (1912–17), when the density of populations in the Laguna area was on the increase, most likely contributed primarily to the spread of the pest northward to the Big Bend and El Paso area of Texas. However, during that time, other infested areas outside the Laguna were known in Mexico. Loftin and others (*14*) stated that the pink bollworm was recognized to be established in three other localities of Mexico outside the Laguna district; Loftin added that one infestation occurred at Santa Rosalia, Chihuahua, at a point about 200 miles south of El Paso. Another infestation was found at San Carlos and Allende (fig. 1).

The infestation was very heavy in the Torreon area in 1960 and 1961. The pink bollworm had built up a resistance to DDT and as a result caused damage of economic significance. However, beginning in 1962 growers used other types of insecticides and the damage decreased. By the 1965 season, it was of no economic significance.

Infestation in the Matamoros area of the Rio Grande Valley was widespread in 1964 and 1965; however, no damage of economic significance was reported.

At San Fernando, some 80 miles south of Matamoros, 65 percent of the fields were infested in 1964, and 95 percent in 1965. However, the average infestation over the entire cotton-growing area of this district amounted to only 4 percent of the area under cultivation; this infestation caused little or no damage to the crop.

Along the Rio Grande, some 114 miles from Matamoros up to Ciudad Miguil Aleman, the infestation covered much of the area, and in 1965, even with 74 percent of the fields infested, the value of the crop was only slightly diminished. The author is indebted to L. R. Ball, PPCD, USDA, (personal communication) for the information about the 1964–65 infestations in Mexico.

Extent of Infestation in the United States

In Texas and Oklahoma

The first infestation of the pink bollworm in the Big Bend area of Mexico and Texas (Presidio and Brewster Counties) was discovered in 1918. However, this infestation was presumably established several years before the infestation at Hearne noted in 1917 and reported by Scholl (*23*).

The prevailing wind in the Laguna area is from the south southeast, particularly at altitudes above 1,000 feet. In analyzing certain infestation data that they collected, Fenton and Owen (*3*) and Fenton (*2*) were able to demonstrate a statistical correlation between wind movement in the Laguna area of Mexico during September and the degree of infestation in cotton on a large farm in El Paso County, Tex. They were able to show that generally the infestations on this farm increased or decreased each year as the total amount of wind movement from the Laguna area of Mexico increased or decreased. In September 1931, record-breaking wind velocities occurred at Tlahualilo, Durango (Laguna area); the pink bollworm infestation in the El Paso Valley that year was the heaviest ever experienced.

Those familiar with the situation in the Laguna area—F. A. Fenton, W. L. Owen, and A. J. Chapman, research entomologists with Oklahoma State University (retired), Texas A. & M. University, and Entomology Research Division, USDA (retired), respectively; and L. F. Curl, R. W. White (retired), and the late H. B. Prickett, of the Plant Pest Control Division—considered that the degree of infestation existing since 1918 in far western Texas and in parts of the lower plains of Texas, New Mexico, and Arizona has been in direct relation to the degree of infestation in the Laguna area of Mexico and the Big Bend area of Mexico and Texas. Their belief was based on an observed correlation of weather information—wind movement, temperature, rainfall, and other interrelated factors—with the presence of infestations in the area. In studying results of surveys conducted to locate new infestations, White concluded that, in general, those areas nearest the Laguna showed the greatest proportion of years in which infestations were found, and that the countries of central Arizona, being farthest from the Laguna, showed the lightest degree of infestation and lowest proportion of years with infestations.

For many years, there has been a heavy infestation in the Presidio Valley caused by local carryover and perhaps by some moth migration from the Laguna of Mexico. According to Rude (*22*), the population of pink bollworms greatly decreased in the Laguna area during the period 1946–51. As a result, there probably was much less moth migration to cotton more to the north, including the Big Bend area. However, by 1960 the infestation was again heavy in the Torreon section of the Laguna, but no corresponding increase was noted in the cotton fields of the Presidio Valley; perhaps the winds were not favorable for moth movement into that area. On the other hand, a well established heavy pink bollworm infestation was discovered in the western part of Maricopa County, Ariz., in 1958, which bears out the fact that the wind movement of pink bollworm moths may have been in that direction rather than toward the Texas-Mexico Big Bend area (L. F. Curl, personal communication).

In the Trans-Pecos section of Texas, north northwest of the Big Bend area of Mexico and Texas, the cotton has been infested with pink bollworm in varying degrees since 1918. The first infestation was probably caused by transporting infested seed cotton from the Candalaria section of the Big Bend area for ginning near Pecos. However, such transportation was stopped by regulatory action. It is believed that the continuous but light, intermittent infestations have been due to moths being carried on the wind from the Big Bend area.

An appreciable part of the early infestation of pink bollworms appearing in the counties northwest of Eagle Pass and Del Rio was probably the result of moth migration from the infested cotton-fields growing in these localities. In fact, the record shows that many of the counties southeast of Lubbock did not become infested until the cotton plantings in the Eagle Pass-Del Rio area became very heavily infested (L. F. Curl, personal communication). The airflow in this area follows the depression of the Rio Grande Valley northwestward and enters the Pecos River and Devils River Canyon, through which it extends northward. This airflow pattern probably aids in transporting moths northward (fig. 1).

One of the most outstanding examples of infestation caused by moth migration occurred on the Chandler Ranch (elevation 1,825 feet) in Terrell County about 50 miles north of the Rio Grande

River in the narrow Pecos River Canyon. Over a period of years, although not continuously, small irrigated acreages of cotton have been planted in this location. The pink bollworm was first found on the Chandler Ranch in the late 1930's. The nearest cotton was about 20 miles north, but the prevailing wind currents from the Eagle Pass cotton area are definitely to the southeast. The author observed a small acreage of cotton there in 1956. Even though no cotton had been planted for 5 years before 1956, by August 29 of that year this field of cotton was very heavily damaged by pink bollworms. The damage indicated that migratory moths had invaded the area much earlier in the season than usual.

The author, in company with L. D. Harris, PPCD, USDA, retired, observed additional evidence of moth migration in isolated fields of cotton 15 miles northeast of Sheffield in bordering Crockett County. Cotton infested with pink bollworm was observed there in 1950, after which year no cotton was planted in these fields until 1954. On November 4, 1954, they noted a rather heavy infestation of pink bollworms. This infestation was apparently the result of moths being carried in the wind currents up the depression of the Pecos River Canyon from the infested Eagle Pass area, which lies to the southeast (fig. 1). Other records indicate that moth migration was general and rather widespread in this area.

In 1947, infestations of pink bollworm were discovered by PPCD inspectors in 30 or more additional counties in Texas and Oklahoma. The rapid spread northward through Caddo County, Okla., covering an area extending from 170 to more than 250 miles from the nearest older infestations of Texas, indicated that moth migration over the area was extensive. Moths were probably carried in the prevailing air currents from the heavily infested area near Eagle Pass and other southern Texas points. (See fig. 3 for wind direction.)

R. W. White and the late H. B. Prickett, PPCD, USDA (personal communications) considered this dispersal to be one of the most striking examples of long-distance flight of pink bollworms ever recorded for this pest in the United States. This seemed to be the only explanation for the simul-

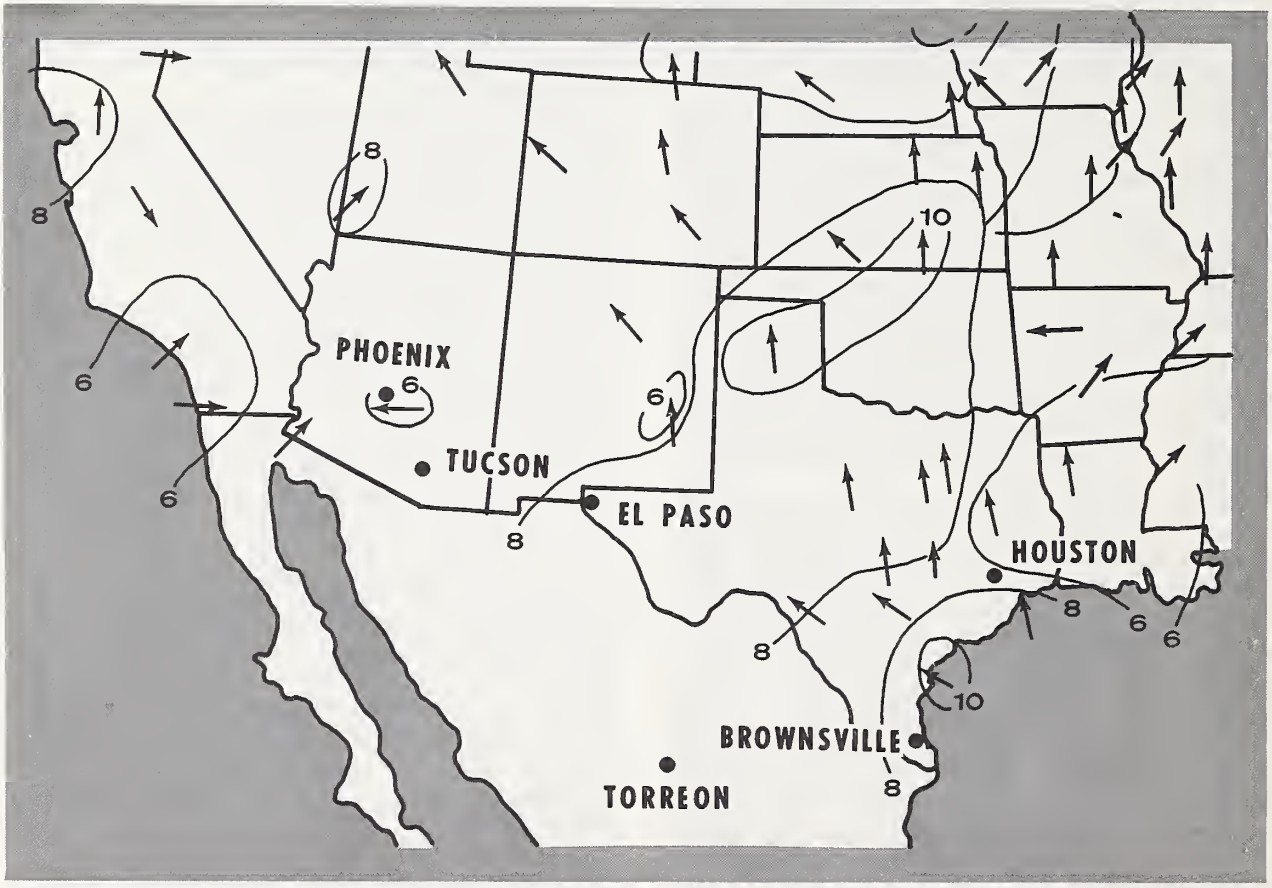

FIGURE 3.—Normal surface wind direction and hourly velocity during July from California to Louisiana. (From Chart VII, U.S. Weather Bureau, Division of Climate and Crop Weather, 1942.)

taneous light infestation that occurred over such a wide area.

The first infestation of pink bollworms in the lower Rio Grande Valley was found at Brownsville, Tex., and Matamoros, Tamps., Mexico, in 1936. The original source of this infestation is not known exactly, although R. B. Lattimore, Plant Quarantine Division, USDA, retired (personal communication), stated that for a number of years preceding 1936, freight cars coming into Matamoros were contaminated with untreated cottonseed, some of which was infested. At the time of discovery, the infestation in the Rio Grande Valley was light. By 1938, the infestation had become more widespread, though still light, since the insect was found to the north in Nueces, Kleberg, and Jim Wells Counties. As the infestations increased in these new localities, they became additional sources for spread. A very high infestation in southern Texas during 1951 and 1952 spread over East Texas and into Louisiana.

During 1951–54, the degree of infestation increased in some 70 counties of Texas located south of Oklahoma. From 1953 to 1954 the infestation extended into some 23 additional counties in Oklahoma. Even though quarantine regulations were carefully enforced, the spread was rapid.[2] The severe drought that caused early maturing of the crop during the summer of 1954 doubtlessly induced dispersal of moths, which in turn was aided by the frequency of southerly winds blowing into Oklahoma from the central Texas area. According to H. G. Johnston, National Cotton Council of America (personal communication), 1949–55 was a critical period of pink bollworm spread.

Even though a program of cultural control has been followed consistently during 1964 and 1965 in Texas, "hot spots" of infestations have been found, as in previous years (D. M. McEachern, PPCD, USDA, personal communication). From 1964 to 1965 (Sept. 1), the infestation in the lower Rio Grande Valley was mostly light to moderate.

During 1964 the population of pink bollworms in the generally infested States of Texas and Oklahoma remained about the same. Populations in eastern Texas and in Oklahoma were lighter than in 1963 (C. C. Fancher, PPCD, USDA, personal communication). However, during 1965 the central counties of Oklahoma were more heavily infested than the western or eastern counties (R. K. Robinson, PPCD, USDA, personal communication). Mr. Robinson added that this situation has prevailed since the State became generally infested, and indicates that moth flight has a bearing on the infestation, since the prevailing winds are from the south southwest.

[2] Before cotton products can be shipped from an infested to an uninfested area, quarantine regulations require that the seed be acid-delinted, fumigated, or heat-treated; that lint cotton be compressed or otherwise treated; and that oil mill linters be treated or fumigated.

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In 1964, heavy populations of the pink bollworm infested the fields in Texas counties of Austin, Caldwell, Colorado, and Wharton (C. C. Fancher, PPCD, USDA, personal communication). Fancher also stated that in the Coyanosa area of Pecos and Reeves Counties, populations were considerably lighter than those recorded in 1963. F. W. Haughton, PPCD, USDA (personal communication), also reported that the infestations in the fall of 1965 in Pecos County were from light to heavy, and that the Imperial infestation appeared to be the heaviest, covering some 500 acres. He added that light to medium infestations prevailed in the Fort Stockton and Coyanosa areas, scattered over approximately 750 to 1,000 acres. The program of cultural control practiced by most cotton growers caused the infestation to be lighter. In 1963, infestations in some fields of this area were as high as 95 percent, but in 1965 most of these same fields were free of the moth. In this area, a voluntary cultural program is now in effect (F. W. Haughton, personal communication).

In the El Paso Valley, a building up of infestation in 1964 caused the El Paso Valley Cotton Association to request that the Texas Department of Agriculture require destruction of stalks by a certain date in El Paso and Hudspeth Counties (C. C. Fancher, personal communication).

Early in the 1965 season, the infestation of pink bollworms was light in Nueces and Kleberg Counties, Texas, but a medium infestation had built up during the latter part of the summer. No great economic damage resulted because of a cleanup program and because the weather was dry (E. F. Sublett, PPCD, USDA, personal communication).

In 1964 and 1965, the counties of Texas making up the Beeville Plant Pest Control Division Work Unit included Aransas, Bee, Refugio, and San Patricio. Inspections in 1964 revealed that only very light infestations of pink bollworms were present in all areas of these counties except for the northwest corner of Bee County, where a very heavy infestation was present throughout the season. This heavy infestation caused crop damage of economic significance in that area. Some observers believed the damage was caused by the late and poor cleanup that growers just across the line in Live Oak County made in 1963. In considering the area of the Work Unit as a whole, the infestation of pink bollworms was heavier in 1965 than in 1964. However, the heavily infested area of Bee County was thoroughly cleaned up in 1964, and in 1965 Bee County had the lightest infestation of pink bollworms of all counties in that Work Unit (C. L. Edgar, PPCD, USDA, personal communication).

During 1964 and 1965, in the Port Lavaca area (Calhoun County) of Texas the infestation was

light, with no damage reported. Nearly all stalks had been destroyed by September so that further infestation was prevented (H. L. Bales, PPCD, USDA, personal communication).

In the Indio Valley of Maverick County along the Rio Grande near Eagle Pass, some plantings were infested during 1964 because considerable rainfall had delayed destruction of stalks the previous fall. This condition resulted in a carryover of infestation in the 1965 season (B. C. Stephenson, PPCD, USDA, personal communication).

Infestation was moderate in the Waco area of McLennan County in 1965, as indicated in light trap collections, and no damage was recorded (C. B. Cowan, Entomology Research Division, USDA, personal communication).

In Arizona and New Mexico

Arizona was first found to be infested with pink bollworms in 1926 near San Simon, Cochise County (fig. 2). Subsequent infestations in eastern Arizona (Safford and Duncan Valleys) were discovered in the same year. Attempts to eradicate the infestations were not successful, although in certain years infestations were below the level of detection. In 1961 a heavy buildup occurred, probably resulting from a high winter survival during the 2 or 3 previous years of exceedingly dry weather with little or no winter irrigation. McDonald and Loftin (*15*) and R. W. White, PPCD, USDA, retired (personal communication), considered that the original infestation was caused by migrating moths airborne from the Big Bend and El Paso areas of Texas, or even perhaps from the Laguna area of Mexico. They pointed out that quarantine efforts had greatly reduced the chances of additional infestation through movement of infested products.

An infestation was first found in the Salt River Valley in Maricopa County in 1929 but was eradicated immediately by a combination of a noncotton zone and other cultural practices which were intensively carried out for several years. Intermittent infestations have occurred in Arizona since that time, with none observed in Maricopa County from July 1947 to 1957; however, in 1958 a very heavy infestation appeared in certain fields in the western part of Maricopa County near Buckeye (*21*). The source of this infestation was not definitely determined.

During June through September, a moderately slow flow of air blows inland from the Pacific toward Yuma in southwestern Arizona (fig. 2). It appears that those Pacific air currents have protected the southern California and Yuma areas and prevented transport of airborne insects from an easterly direction. This condition would most likely create the possibility of a fallout of insects carried in these winds over the Tucson-Phoenix area (fig. 2). However, in April 1960 one female pink bollworm moth was taken in a blacklight trap fitted with an argon lamp near the town of San Luis in the lower Yuma Valley (*21*), and in March 1961 another female was taken near Hyder, just inside the eastern edge of Yuma County (*1*). The source of the moths could not be determined since no infestation had ever been found in cottonfields in these areas. However, the circulation of air is not so consistent as to preclude the possibility of insects being carried toward and into California by an occasional easterly wind. During September and October 1965, this condition apparently did occur with a high percentage of wind circulation from an easterly direction. These easterly winds most likely resulted in the dispersal of pink bollworm moths into Yuma County and into California across the Colorado River. During October, 14 moths were taken in traps baited with sex lure at Bard (Imperial County), Calif., across the Colorado River from Yuma, Ariz.; and 4 moths at Blythe, Calif. (Riverside County), some 60 miles (by air) north of Yuma (fig. 2). On October 20, a larva was found in a green cotton boll near Hyder in eastern Yuma County, Ariz., and on October 22 another larva was found in the same field.

In 1965, according to Karl S. Rohwer, PPCD, USDA (personal communication), heavy infestations were present in the vicinity of Wintersburg, in Rainbow Valley in the vicinity of Buckeye, and at several other locations in the eastern part of Maricopa County near Mesa. The infestations continued to be heavy and apparently resulted in a general dispersal of moths westward into Yuma County down the Gila River Valley (fig. 2). Rohwer added that farmers who pilot their own airplanes from airstrips in the Gila River Valley in the eastern part of Yuma County reported that strong winds blew from the east just before and during the first week of October. Their reports coincided with the period when pink bollworm moths were first caught in the area. The U.S. Weather Bureau reported easterly winds aloft up to 4,000 feet at Tucson, Ariz., 17 days in September, and 14 of the first 20 days in October. However, easterly winds reaching Yuma had decreased considerably in velocity, with the velocity averaging 7.8 miles per hour on only 4 of the first 15 days in October. Thus prevailing Pacific winds tended to prevent or block easterly winds from continuing very far into California (fig. 2).

During 1958 through 1963 an extensive program, combined with cultural practices, was conducted to control pink bollworms in central Arizona. In 1964 a widespread light infestation was found in Maricopa and Pinal Counties. During this year, Graham County had the heaviest infestation ever encountered in Arizona; in a few fields in the county, 60 percent or more of the cotton was damaged (*16*). By September 1, 1965, the

infestation was still widespread but was reduced with an insecticide program (G. P. Wene, University of Arizona, personal communication). Even if eradication were successful for a given period, the author believes that as long as infestations are as close as those in Graham County, reinfestation will probably occur in central Arizona from the moths that are transported on the air from that county.

In New Mexico, a damaging infestation of pink bollworms occurred in 1964 south of Carlsbad in southern Eddy County. Surveys in 1965 showed that an infestation of about the same intensity was present in this area. Surveys in 1964 and 1965 revealed that populations of pink bollworm had increased in cotton growing along the Mexican border at Columbus and in southern Luna Counties. However, infestation was present in all cotton-growing areas in the State (G. F. Fulkerson, PPCD, USDA, personal communication).

Reinfestation in Arizona and New Mexico seems possible by wind carriage of moths, even hundreds of miles away from extreme west Texas or northern Mexico.

In Arkansas and Louisiana

The pattern of infestations in Arkansas strongly suggests that moths are carried there on the wind. The insect was first discovered in 1953 in Hempstead and Miller Counties in the southwestern corner of the State. Since that time, several other counties adjacent to the Oklahoma border as well as scattered areas throughout the State have become infested. Charles Lincoln and R. C. Hunter, University of Arkansas (personal communications), considered that a reasonable explanation of this dispersal pattern may be that the moths were windborne in a northerly direction out of Texas, with Arkansas being on the eastern margin of the flight. This reasoning seems logical, since more pink bollworms were found in those counties of Arkansas that touched Oklahoma than in counties located farther away.

According to the U.S. Weather Bureau, prevailing air currents in an area of the Arkansas River Valley are directed up the valley toward the Oklahoma State line (fig. 3, arrow pointing westward in Arkansas). This condition is caused by southerly surface winds that blow over the low-lying Ouachita Mountains, south of the Arkansas River, and then are deflected westward by the buffering action of the Ozark Mountains adjacent to the north side of the Arkansas River Valley. However, the presence of winds prevailing up the valley does not rule out the possibility (as observed by Lincoln and Hunter, personal communication) that at certain times moths could be carried down the valley. At night a layer of air colder than other layers will often flow down a valley instead of up, and thus could carry the moths in a reverse direction.

The pattern of infestation in the rest of the State strongly suggests that moths are carried on the wind in a northeasterly direction from south-central Texas. Lincoln and Hunter, University of Arkansas (personal communications), considered that the pattern of infestation did not fit one carried by man. U.S. Weather Bureau data show that prevailing winds at 1,000 to 3,000 feet, mostly directed toward the north and northeast throughout the summer and fall months, travel at a velocity of 6 to 8 miles per hour (fig. 3). These prevailing winds above 1,000 feet should be a means of transporting moths in a northeasterly direction from south-central Texas. No infestation was found in Arkansas in 1961, and only light infestations were present in 1962. In 1963, however, infestations increased in some 20 counties scattered over the State. In 1964, however, the infestation was limited to the counties of Yell and Miller, with only two pink bollworms recovered in these widely separated counties. In 1965 (up to Sept. 1) no infestation was found in Arkansas (C. C. Fancher, PPCD, USDA, personal communication).

SUMMARY

Studies and observations of the progression and spread of the pink bollworm in the United States and Mexico have been compiled and correlated with other information available. Some of the information dates as far back as 1911, when the insect was presumably introduced into Mexico from cottonseed shipped from Egypt. Many large infestations were spread by migration of moths, as indicated by (1) collections taken during airplane flights and from light traps, (2) observations of infestations present on isolated plantings of cotton, and (3) studies of effects of wind and other weather factors on moth movement. Collections made during airplane flights established that moths were present in the air at heights ranging from near the surface to 3,000 feet. Light traps have caught pink bollworm moths in areas many miles distant from the nearest known infested cotton. Isolated trap plots planted at least 65 miles from the nearest cotton were found to be infested with the insect. The presence of these infestations could be explained only by considering that the moths had flown or been carried on the wind from that area.

Other studies showed that moths can establish an infestation after being exposed to conditions simulating weather in the upper air for 1 to 7 days. The female moths remained in good condition and were able to begin or resume oviposition.

The 1947 spread northward over several counties of Texas and western Oklahoma, 170 to 250 miles from the infested counties in Texas, could be accounted for only by migration.

Numerous observations of his own as well as those reported by others lead the author to conclude that infestations of this important cotton insect can be spread considerably by natural means. Dispersal of the insect in this manner, coupled with a rapid rate of increase and a high potential to survive, make the problem of controlling this destructive cotton pest difficult to solve.

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